JAPANESE PATENT OFFICE (JP)

PATENT JOURNAL (A)

KOKAI PATENT APPLICATION NO. HEI 1[1989]-187505

Technical Indication Section

Int. Cl.^{4}:	G 02 B 6/00
Identification code:	326
Sequence Nos. for Office Use:	7370-2H
Application No.:	Sho 63[1988]-10942
Application Date:	January 22, 1988
Publication Date:	July 26, 1989
No. of Inventions:	4 (Total of 6 pages)
Examination Request:	Not requested

A LIGHT-DIFFUSING TUBE AND A MANUFACTURING METHOD THEREOF

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[There are no amendments to this patent.]

Specification

1. Title of the invention

A light-diffusing tube and manufacturing method thereof

2. Claims of the invention

(1) A light-diffusing tube in which a transparent tubular body having the surface roughness of the inner wall in the range of 0.01 to 0.6 μm in terms of the mean center line roughness Ra is filled with a core material with a refractive index higher than that of the tubular body, and at least one end of the tubular body is used as a light-collecting section, and the peripheral surface is used as a light-diffusing section.

(2) The light-diffusing tube specified in claim 1 above wherein both ends of the transparent tubular body are closed with a window material.

(3) The light-diffusing tube specified in claim 2 above wherein a transparent window material is used for one end to form a light-collecting section, and a light-reflecting component is used for the other window.

(4) A method of manufacturing the light-diffusing tube specified in one of claims 1 through 3 above wherein a core material in a non-cured state is used to fill the interior of a transparent tubular body and curing or semi-curing of the above-mentioned core material is carried out.

3. Detailed explanation of the invention

Field of industrial application

The present invention pertains to a light-diffusing tube having the capability of converting highly collimated rays of light to rays of light that are highly diffuse, and the above-mentioned light-diffusing tube is used in the field where sun light is transmitted through an optical transmission path to be utilized, namely, in areas where a solar system is utilized such as offshore farming, vegetable plants, artificial breeding room, hospitals, city dwellings; and, upon connecting the end to a light emitting photoconductive tube or directly connecting to a lamp house, in the field where artificial light is transmitted through the light transmission path, namely, hazardous substance storage facilities, gateways, chemical plants, pipe lines, underwater illumination, lighting used for handling of hazardous substances.

Prior art

Properties required for light or light sources vary significantly depending on the application, and the most appropriate light source is selected taking factors such as brightness of light, wavelength distribution, uniformity, collimation, heat formation, life of the light source and cost into consideration.

In order to transmit light over a long distance, a light source with high collimation is required, in which case, optical means such as lenses or a light transmission path such as optical fibers are used to transmit the light to the area required, and for example, in the case of a system that utilizes sunlight, as a means to transmit sunlight at low cost, the sunlight focused with a lens is introduced to an optical fiber. However, the above-mentioned light focused with a lens or light transmitted by optical fiber has high directionality, and the intensity of the light is too high and is physiologically unpleasant; furthermore, the application space of the light is reduced. Thus, it is desirable to convert the above-mentioned spot light with high collimation or high directionality into a diffuse light with high spatial distribution from a surface light source or tubular light source at the area where it is required so as to remove the physiological discomfort.

The light obtained from a xenon lamp has a wavelength distribution similar to that of sunlight; thus, it is a suitable light source for human beings, but in order to be used as the light source for vegetable plants, artificial breeding rooms, incubators, etc., it is desirable to convert the spot light into the above-mentioned surface light source or tubular light source.

A fluorescent lamp is an inexpensive tubular light source, and has a relatively high spatial distribution of light, but the luminous spectra includes bright lines and it lacks suitable optical components required for growth of vegetables, resistance to external physical force is poor, and it is likely to become an ignition source, it generates heat, etc., and therefore, the application range is limited, or a special protective device is required.

Problems to be solved by the invention

Based on the above background, the objective of the present invention is to produce a simple and inexpensive lighting device capable of converting rays of a light with high collimation to rays of light with a high diffusion.

Furthermore, the present invention is to provide a simple method capable of producing the above-mentioned lighting device.

Means to solve the problems and effect

According to the present invention, the above-mentioned objective can be achieved through a light-diffusing tube wherein a transparent tubular body having an interior wall surface roughness in the range of 0.01 to 0.6 μm in terms of the mean center line roughness Ra is filled with a core material having a refractive index higher than that of the tubular body, and at least one end of the tubular body is used as a light-collecting section, and the peripheral surface is used as a light-diffusing section.

In the above-mentioned light-diffusing tube, a light with high directionality enters the core material from the light-collecting section located at one or both ends of the light-diffusing tube. The refractive index of the core material is higher than the refractive index of the tubular body, and the light undergoes refraction and reflection at the inner wall of the tubular body, that is, at the contact boundary between the tubular body and core material, but when the boundary surface is flat, a high proportion of light is reflected, and when the angle of incidence at the boundary surface exceeds the critical angle, total internal reflection occurs and the light travels inside the core material while maintaining directionality.

However, the center line roughness Ra at the above-mentioned boundary, namely, the interior wall of the tubular body is in the range of 0.01 to 0.6 μm; thus, in many cases, the light that enters the inner wall from the core material side undergoes refraction and enters the tubular body, and even in the case of reflection, the light enters a different part of the interior wall and undergoes further refraction at a different point and enters the tubular body. In this manner, the refracted light from the above-mentioned tubular body is emitted over the entire peripheral surface of the tubular body. Furthermore, the above-mentioned light is refracted by the irregular rough surface, thus, the light lacks directionality, and a light with a high spatial distribution with the peripheral surface of the tubular body acting as a tubular light source can be achieved.

It is important that the surface roughness of the above-mentioned interior wall be in the range of 0.01 μm to 0.6 μm in terms of the center line roughness Ra. When the Ra is 0.01 μm or below, emission of light from the peripheral surface of the tubular body is not possible to any practical degree, and when Ra exceeds 0.6 μm, a significant degree of localization in the distribution of the light intensity in the longitudinal direction of emission from the peripheral surface of the tubular body occurs; thus, it is not practical. It should be noted that the center line roughness Ra is one notation commonly used for surface roughness (see JIS B 0601 for reference), and when the center line of the roughness curve (in other words, the line where the area between the line and the roughness curve is equal on both sides), where, on the x-axis and the roughness curve is defined as y=f(x), Ra is determined by the formula shown below in units of microns.

//please insert (a) //

$$R_a = \frac{1}{l} \int_0^l |f(x)| dx$$

l is the standard measured length.

In the above-mentioned light-diffusing tube, when both ends of the transparent tubular body are closed with window materials, it is effective to maintain and protect the core material at a specific location.

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Furthermore, when a transparent material is used for the window material at one end and is used as a light-collecting section, and a light reflective material is used for the window material at the other end, light does not escape from the other end does; thus, nearly all of the light that enters the light-diffusing tube is released from the peripheral surface of the tubular body; as a result, the light conversion ratio is increased.

As described above, the light-diffusing tube of the present invention can be easily produced when a non-cured state core material is used to fill the interior of a transparent tubular body and curing or semi-curing is performed for the above-mentioned core material.

Application examples

In the following, the present invention is explained further in specific terms with application examples and drawings. Fig. 1 is a cross section view that shows a model of an application example of the present invention, and light-diffusing tube 1 has a structure consisting of transparent tubular body 2 filled with core material 3, and the openings on

both ends of the tubular body are closed with window materials 4 and 5. The tubular body is made of a transparent organic or inorganic material, for example, glass, quartz, alumina, polyethylene, polypropylene, polyester, polyamide, silicone rubber, polycarbonate, polyvinyl chloride, tetrafluoroethylene, hexafluoropropylene copolymer, tetrafluoroethylene perfluoroalkoxy ethylene copolymer, etc. Core material 3 is also made of a transparent material, and for the core material, in addition to plastics, thermoelastomers, cured liquid material, and liquid materials can be used as well. When a liquid material is used for the core material, it is desirable to use a viscous liquid or semi-solid liquid since it is important for the liquid material to be securely contained in the tubular body for a long period of time. In specific terms, polyols such as polyethylene oxide, polypropylene oxide, and glycerol, polyol esters, polyol ethers, phosphates such as tris(chloroethyl)phosphate, tris(dichloropropyl)phosphate, liquid paraffin, fluorine oil, silicone oil, polyisobutylene, polysiloxane-modified polyether, etc. can be mentioned.

Furthermore, a material produced by filling a curable liquid material inside the tubular body, and curing is subsequently carried out at room temperature, using heat, light, or radiation to cue the core material.

For the above-mentioned curable liquid material, epoxy resins, liquid silicon, polyurethane, liquid polybutadiene, etc. can be mentioned. When the core material is produced as described above, light-diffusing tube 1 with core material 3 in close contact with the inner wall of tubular body 2 with a rough surface can be produced easily.

The window material is a transparent material used for sealing the core material inside the tubular body, at the same time, the light enters the light-diffusing tube through

the window material. The materials that can be mentioned for use as the above-mentioned window material are quartz, crown glass, flint glass, chalcogenite type glass, sapphire, crystal, polycarbonate, methacrylic resin, polystyrene resin, etc.

The main function of window material 5 used for the opposite end of core material 4 is enclosure of core material 3, and it is not necessary for the material to be a transparent material, but when the light is to be emitted from the end as well as along the peripheral surface of the tubular body, or when light is to be brought in from core material 5 as well, a transparent material can be used for core material 4 as well.

The refractive index for the wavelengths of the transmitted light is different for the material used for the above-mentioned tubular body and the material used for the core material, and the refractive index of the material used for the core is higher than the refractive index of the material used for the tubular body. However, it is not necessary for the tubular body to have a refractive index lower than the refractive index of the core material throughout its thickness, and it is sufficient for the refractive index of the material at and near interior wall 6 in contact with the core material to be lower than the refractive index of the material used for the core material.

Furthermore, a rough surface is used to form interior wall 6 of the tubular body as shown in Fig. 2, and the surface roughness is defined to be in the range of 0.01 μm to 0.6 μm in terms of the above-mentioned Ra. Each ray of light that enters light-diffusing tube 1 through window material 4 travels inside core material 3 as shown by i_1, i_2, and i_3 in Fig. 2, during the course of travel, a part of light is refracted at the boundary between the tubular body and core material, that is, at interior wall 6 of tubular body 2, and enters the tubular

body, and a part is reflected and continues inside the core material. The refracted rays of light enter the tubular body in the thickness direction, and are emitted from peripheral surface 7, and the ratio and angle of the refracted light and reflected light vary depending on the slope of the roughness curve of the inner wall, as a result, the refracted light from the peripheral surface is released over the entire surface at essentially the same intensity and uniformity in all directions.

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However, when the surface roughness Ra of interior wall 6 is 0.01 μm or below, it is virtually impossible for light to be emitted from peripheral surface 7 of the tubular body. On the other hand, when Ra exceeds 0.6 μm, significant variations occur in the intensity distribution of the light emitted from the peripheral surface of the tubular body along the tube in the longitudinal direction; thus, it is important for the surface roughness Ra of the interior wall to be in the range of 0.01 μm to 0.6 μm. The above-mentioned degree of surface roughness can be achieved by a mechanical treatment of the inner wall such as liquid honing or a plasma etching treatment; furthermore, the same effect can be achieved through appropriate control of the thermal shrinkage ratio or other factors at the time of extrusion of the tubular body.

Fig. 3 shows an example where a metal material is used for window material 5 and the interior end surface is polished to form light-reflecting mirror surface 8. In the above-mentioned structure, the rays of light entering window material 4 that reaches window material 5 without being emitted from the peripheral surface 7 of the tubular body re-enter the core material, and are converted to diffuse rays of light emitted from the peripheral

surface via interior wall 6; as a result, the light conversion efficiency can be increased. For materials used for window material 5, metal materials such as stainless steel, aluminum, brass, and iron can be mentioned. Furthermore, a material such as glass or resin, in which mirror surface cannot be achieved through polishing of the material itself, is used as window material 5, and a metal thin film is deposited onto said surface by means of deposition, sputtering, or plating to produce the light reflective surface 8.

Fig. 4 shows an example where light-reflecting film 9 is formed on the outer surface of window material 5. The material used for the window material is a clear quartz, etc., and light-reflecting film 9 is produced by depositing a thin metal film on the end face of the above-mentioned window material by means of deposition, sputtering, plating, or by applying a thin film made of a material such as aluminum or copper to the window material.

The inventors produced a prototype light-diffusing tube of the present invention as shown in the following test examples 1 and 2, and confirmation of the effect was achieved.

Test Example 1

As the above-mentioned tubular body 2, a hollow tube made of tetrafluoroethylene-perfluoroalkoxy ethylene copolymer resin and having an inner diameter of 2 mm, an outer diameter of 4 mm, and a length of 300 mm was used, and tris(monochloroethyl)phosphate was filled inside the above-mentioned tube as core material 3, and both ends of the tube were closed with a quartz stopper having a diameter of 3 mm and length of 30 mm. When the degree of surface roughness of the inner wall of the above-mentioned hollow tube was

measured by the tracer method using a surface roughness meter SURTRONIC (product of Taylor-Hopson Corp.), it was found that Ra = 0.17 μm was achieved.

The rays of light from a halogen lamp were applied to one end of the above-mentioned light-diffusing tube, and the brightness of the peripheral surface of the light-diffusing tube was measured with a luminosity meter (product of Minolta Corp.). The measured area was at intervals of 50 mm from the window material. The results obtained are shown in the upper row of Table I below.

Test Example 2

A material produced by sputtering a thin film of aluminum onto the end surface of a quartz stopper having a diameter of 3 mm and length of 30 mm as the window material for the opposite end from that where the rays of light enter (core material 3 in Fig. 3 above), and a light-diffusing tube similar to the one used in test example 1 was produced and the same test was performed. The results obtained are shown in the lower row of Table I below.

Table I

Distance from window material 4 (mm)	50	100	150	200
Brightness (cd/m^2) Example 1	—	410	235	201
Brightness (cd/m^2) Example 2	—	710	510	550

In this manner, it was confirmed that a uniform tubular light source with a high brightness can be achieved through the present invention.

Effect of the invention

As explained above, in the light-diffusing tube of the present invention, a transparent tubular body having an interior wall with a surface center line roughness Ra in the range of 0.01 to 0.6 μm is filled with a core material having a refractive index higher than that of the above-mentioned tubular body, and at least one end of said tubular body is used as the light-collecting section; thus, rays of light with a high collimation or high directionality can be efficiently converted to rays of light with a high diffusion so that the above-mentioned peripheral surface can be used as a tubular light source.

Furthermore, the core material is positioned and protected at the specified position by the window materials; thus, the life of the material can be extended.

In addition, when a transparent material is used as the window material on one end and a light-reflecting material is used for the window material on the other end, it is possible to convert the incident light into rays of light with high diffusion with a higher efficiency.

The light-diffusing tube of the present invention can be produced easily when a core material in a non-cured state is used to fill a transparent tubular body and curing or semi-curing is performed for the above-mentioned core material.

4. Brief description of figures

Fig. 1 shows a vertical cross section view of the light-diffusing tube of an application example, Fig. 2 shows an enlarged vertical cross section view of a portion of

the above-mentioned light-diffusing tube with the focus on the rough surface; Fig. 3 and Fig. 4 each show vertical cross section views of different application examples of the present invention.

1 ... Light-diffusing tube

2 ... Tubular body

3 ... Core material

4 ... Window material

5 ... Window material

6 ... Interior wall

7 ... Peripheral surface

8 ... Light reflecting surface

9 ... Light reflecting film.

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Fig. 1

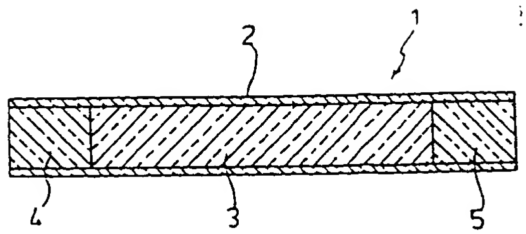

Fig. 2

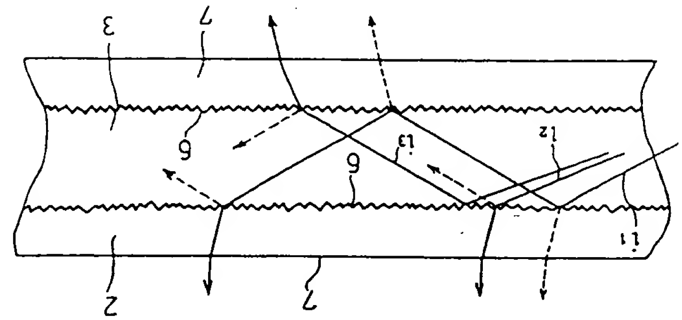

Fig. 3

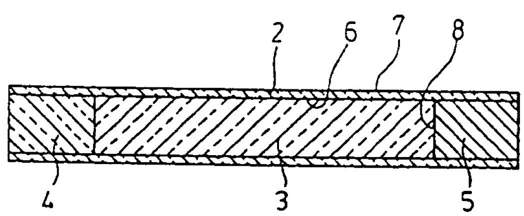

Fig. 4